Available online at www.sciencedirect.com
ScienceDirect
Renewable and Sustainable Energy Reviews
12 (2008) 1345–1363
RENEWABLE
& SUSTAINABLE
ENERGY REVIEWS
www.elsevier.com/locate/rser

Solar photovoltaic (PV) on atolls: Sustainable development of rural and remote communities in Kiribati

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Received 22 December 2006; accepted 23 January 2007

Abstract

On the remote and geographically fragmented atolls of Kiribati (Republic of), imported petroleum products are the main sources of energy. The other sources of energy utilised include biomass, solar energy and wind power. Of these three renewable energy sources, biomass is the most, and wind power is the least, exploited in terms of the contribution it makes to the total primary energy supply. Solar energy makes a very insignificant contribution to the total primary energy supply in Kiribati. Petroleum products, biomass and solar energy contribute approximately 75%, 25% and less than 1%, respectively to the total primary energy supply annually. Solar energy has been exploited mostly in the form of photovoltaic (PV) technologies for the provision of lighting.

The geographical, social, economic and political situation in Kiribati is considered in this paper to give an overview of the country. The current energy situation in Kiribati is presented with emphasis on the application of PV technologies. Some recommendations that will promote sustainable development of the rural and remote communities on the outer atolls of Kiribati, through the use of PV technologies, are also presented in this paper.

Keywords: Kiribati; Renewable energy; Solar energy; Photovoltaic (PV); Rural and remote communities

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1364-0321/$ - see front matter
doi:10.1016/j.rser.2007.01.019

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1. Introduction

Access to basic energy services is recognised as an essential element in daily lives. In developed countries (or modern societies), the increase in per capita energy consumption has been considered as a measure of economic development. In most developing countries (especially in rural and remote communities), lack of access to energy services has been seen as a hindrance to development.

Over the past two decades, developing countries have attempted to improve and sustain energy services through a number of approaches such as the introduction of modern forms of energy supplies, restructuring power utilities and educating communities about energy supply systems [1]. Momentum for these approaches has been provided in the form of funds for energy projects [1]. Most of these energy projects in developing countries have focussed on the delivery of electricity or other energy services based on the assumption that development will follow [2]. To understand and appreciate the benefits provided by energy services, it is important to see them in the context of their contribution towards the development of communities.

The main objectives of this paper are to review the current applications of photovoltaic (PV) technologies in Kiribati and to suggest how they can contribute towards sustainable development of the communities on the outer atolls.[1] The geographical fragmentation,

[1]All the atolls (including Banaba Island) except South Tarawa are referred to as outer atolls. North Tarawa is also referred to as an outer atoll. Section 2.1 (Geography) contains more discussions on the outer atolls.

remoteness and small size of Kiribati are fundamental constraints to its development. The population of Kiribati has grown in the past decade. Coupled with this population growth is the dramatic increase in energy demand [3]. Petroleum products are the main source of energy supply in Kiribati. PV technologies were introduced in Kiribati in the late 1970s [4]. At that time, PV was used for communication purposes, lighting and water pumping on a very small scale [4].

The first part of this paper gives an overview of the country by presenting the geographical, social, economic and political situation in Kiribati. The section that follows presents the existing energy scenario of Kiribati in terms of its energy and electricity demand and supply, and the prevailing energy framework. The availability of the solar energy resource and current applications of PV technologies are then presented. Finally, recommendations are given on how PV technologies can be further integrated into sustainable development of the outer atoll communities in Kiribati.

2. Country overview

2.1. Geography

The Republic of Kiribati, formerly known as the Gilbert Islands, is a Micronesian[2] country in the Pacific. Fig. 1 shows a map of Kiribati and its location at geographic coordinates 1°25′N and 173°00′E [5]. Kiribati consists of 32 atolls and only one raised coral island divided into the following three groups:

- Gilbert group—16 atolls and one raised coral island located approximately 1500 km north of Fiji Islands;
- Phoenix (Rawaki) group—8 atolls located 1800 km southeast of the Gilbert group; and
- Line group—8 atolls located 3300 km east of the Gilbert group.

These three groups comprise a total land area of 811 km^2, which are spread over 13 million km^2 of the Pacific Ocean [6]. Such a small land mass distributed in such a large ocean space is an indication of the huge distances between the atolls. The 32 atolls are only a few metres (with some places as low as 2 m) above sea level, making the atolls vulnerable to sea level rises and coastal erosion [7,8]. The highest peak (only 87 m) is on Banaba (Ocean) Island in the Gilbert group [7]. Banaba Island is the only raised coral island in Kiribati and once was one of the three richest sources of phosphate deposits in the Pacific [7]. Kiritimati (Christmas) Atoll in the Line group is the largest atoll in the world. Kiritimati Atoll has a land area of approximately 642 km^2, which is about 80% of the total land area of Kiribati [8]. Based on the 1995 realignment of the International Date Line (IDL), Kiribati is now the easternmost country in the world, and was the first country to enter into the year 2000 at Caroline Atoll (an uninhabited atoll in the southern part of the Line group) which has been renamed Millennium Island [8].

[2]One of the three groups of islands in the Pacific. The eight territories that make up Micronesia are Commonwealth of the Northern Mariana Islands, Federated Sates of Micronesia, Republic of Kiribati, Republic of the Marshall Islands, Republic of Nauru, Republic of Palau, Territory of Guam and Territory of Wake Island. The other two groups of islands in the Pacific are Melanesia and Polynesia.

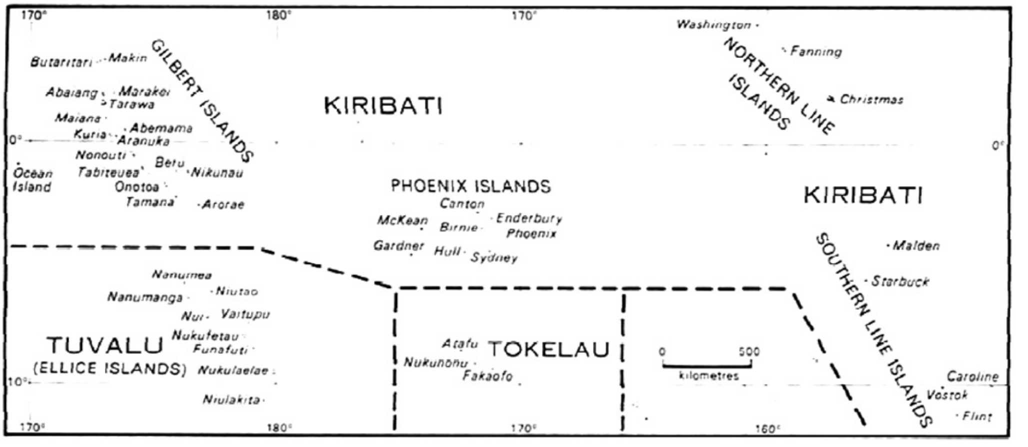


Fig. 1. Map of Kiribati (showing the three island groups: Gilbert, Phoenix and Line) and other neighboring territories (Tuvalu and Tokelau) in the Central Pacific.

2.2. Socio-economic situation

Most of the atolls of Kiribati are flat ribbons of sand surrounded by extensive reefs with scarce fresh water supplies and limited vegetation [9]. Fig. 1 shows the different atolls (including Banaba Island) in their respective groups. Human habitation is restricted to only 21 atolls. The inhabited atolls are as follows:

- 17 in Gilbert group—all 16 atolls and Banaba Island;
- 1 in Phoenix group—Kanton Atoll; and
- 3 in Line group—Kiritimati, Tabuaeran and Tereina Atolls.

These 21 inhabited atolls are home to a number of villages. The size and the number of villages vary from one atoll to another. According to the statistics provided by the Kiribati National Statistics Office, the population of Kiribati in 2005 was 92 533 [10]. About 90% of the population lives on the Gilbert group, of which most live on South Tarawa [8]. The population of South Tarawa (including Betio Islet: refer to discussion in subsequent paragraph) in 2005 was 40 311.

South Tarawa is an islet of Tarawa Atoll and is the capital of Kiribati. Fig. 2 shows a map of Tarawa Atoll [11]. Tarawa Atoll consists of 24 islets of which at least eight are inhabited [11]. South Tarawa is the largest islet, which extends from Bonriki to Bairiki Village. The main urban centres on South Tarawa are at Bikenibeu and Bairiki Village. Approximately 3.5 km of causeway (Nippon causeway) connects Bairiki Village to Betio Islet. Betio Islet has a major urban centre consisting of various commercial, government and industrial sectors.

Kiribati is categorized as a least developed country (LDC) due to its low per capita gross domestic product (GDP) [3]. The statistics available from the Asian Development Bank (ADB) show that the total value of GDP 'by industrial origin'[3] of Kiribati 'at current

[3]GDP 'by industrial origin'—GDP disaggregated into the industries in which it is produced. This also includes import duties. Industries are generally defined in conformity with the International Standard Industrial Classification (ISIC).



Fig. 2. Map of Tarawa Atoll (Courtesy of South Pacific Travel Guides).

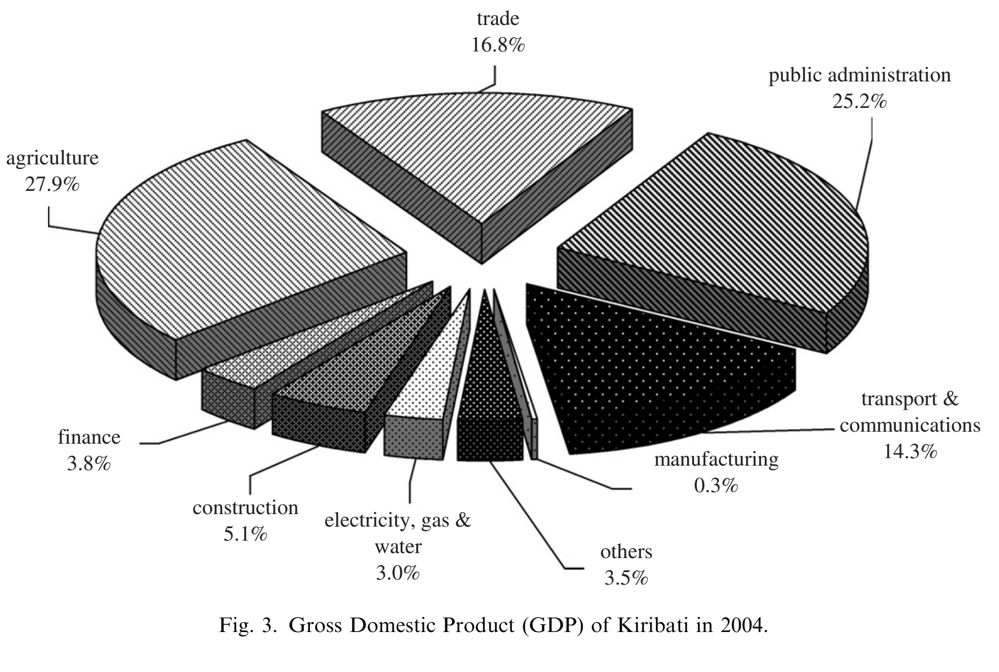


Fig. 3. Gross Domestic Product (GDP) of Kiribati in 2004.

factor cost'[4] in 2004 was AU$28.7 million [3]. Fig. 3 shows GDP of Kiribati for the various sectors [3]. The agricultural sector was the largest contributor accounting for approximately AU$8.0 million. A significant contribution was made by the public administration sector as well. The electricity and gas (including water) sector contributed approximately AU$876 000. The manufacturing sector contributed the least, accounting for only about AU$95 000.

The arid climate and poor soil restrict the *I-Kiribati* (people of Kiribati) from engaging in large-scale agriculture [7,8]. The economy is dependant on copra, fish, seaweed, licence

[4]GDP 'at current factor cost'—GDP as measured at current market prices instead of constant prices.

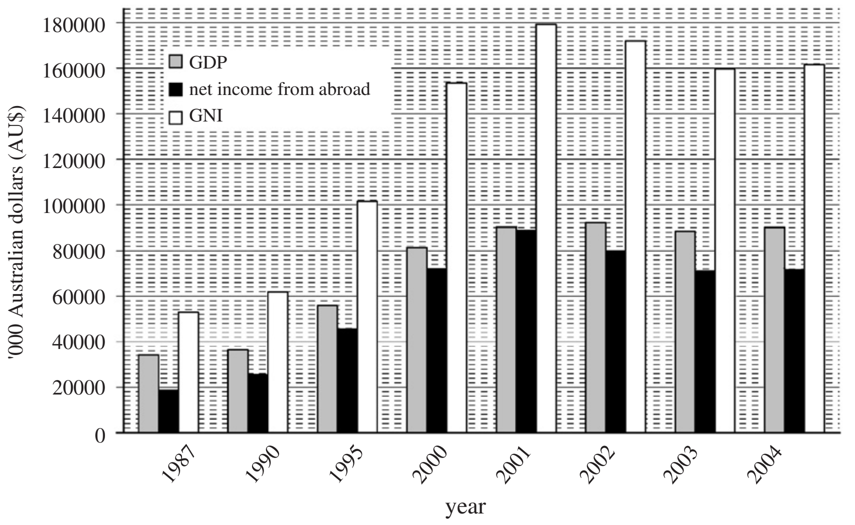


Fig. 4. Gross Domestic Product (GDP), net 'income from abroad' and Gross National Income (GNI) of Kiribati for 1987, 1990, 1995, 2000–2004.

fees from foreign fishing fleets, foreign aid and earnings from the Revenue Equalization Reserve Fund (RERF) [12]. The RERF was established in 1956 with royalties from phosphate mining [12]. The initial amount was AU$550 000 and it has grown steadily over the years [12]. In 1979, the RERF was AU$56 million and at the end of 2001 it was AU$635 million [12].

According to the ADB statistics, the gross national income (GNI) of Kiribati was almost twice its GDP in 1987, 1990, 1995, 2000–2004 [3]. Fig. 4 Shows the GDP, 'net income from abroad'[5] and GNI of Kiribati for the respective years. The large GNI in comparison to the GDP is because of substantial income from abroad and earnings from the RERF. Kiribati enjoys a strong international financial position because the income from RERF covers the deficits. In 2002, the GNI decreased due to a lower value of the 'net income from abroad'. In 2003, both the GDP and 'net income from abroad' decreased resulting in a lower GNI. Increase in GDP and 'net income from abroad' in 2004, improved the GNI in 2004.

Most of the economic activities are confined to South Tarawa (including Betio Islet).[6] Recently some developments have taken place on Kiritimati Atoll because of tourism. The economies on the other outer atolls are mostly subsistence. About 80% of households make a living through fishing [9].

2.3. Political situation

Kiribati is a republic, having gained its independence from the United Kingdom on 12th July 1979. The Parliament of Kiribati (*Maneaba ni Maungatabu*) is elected every 4 years.

[5]'Net income from abroad'—consists of the earnings from RERF and the financial support received from donor agencies.

[6]From here onwards, when South Tarawa is mentioned in the discussions, it also includes Betio Islet (except where stated).

Elections take place in two main phases; the general election and the presidential election. In the general election, the 41 atoll-based constituencies vote for their respective members of parliament (MPs) [9]. Following this, these 41 MPs nominate three or four MPs as candidates for the president (*Te Beretitenti*). The presidential election then takes place 35 days later [9]. The term of office for both the president and the house of parliament are 4 years and a president can serve a maximum of three terms.

The government is based on a combination of British Westminster principles and local traditional values [8]. There is one local Island Council for each of the 21 inhabited atolls (including Banaba Island), except Tarawa Atoll. Tarawa Atoll has three local councils: Betio Town Council (for Betio Islet), *Eutan* Tarawa Council (for North Tarawa) and *Te Inainano* Urban Council (for South Tarawa). These Island Councils are made up of the village leaders. Some larger villages have more than one leader. In such cases, all the village leaders are representatives on the Island Council.

3. Energy scenario

3.1. Energy sources and demands

The energy sources utilised in Kiribati consist of petroleum products, biomass, solar energy and wind power. Of these four sources, petroleum products are the most, and wind power is the least, utilised in terms of their contribution to the total annual primary energy supply. Sections 3.1.1–3.1.4 discuss each of these energy sources and the demands that exist for them in Kiribati.

3.1.1. Petroleum products

In Kiribati, petroleum products account for approximately 75% of the total primary energy supply annually [13]. There are no indigenous sources of petroleum products in Kiribati. Therefore, Kiribati is heavily dependant on imported petroleum products, which are used for cooking, electricity generation, lighting and transportation (air, land and sea). The petroleum products used in Kiribati are [14]:

- Automotive diesel oil (ADO);
- Aviation gasoline (Avgas);
- Dual purpose kerosene (DPK);
- Jet aviation fuel (JetA-1);
- Liquefied petroleum gas (LPG)—sold as KIRIGAS (by Kiribati Gas Company) and KOIL Gas (by Kiribati Oil Company);
- Unleaded petrol (ULP).

ADO is used as fuel in the trucks and to power generators for electricity production.[7] There are a number of trucks on South Tarawa and the outer atolls. DPK is used for cooking on all the atolls and for lighting mainly on the outer atolls. DPK is also used as an aviation fuel. LPG is used for cooking mainly on South Tarawa. Small-scale demands for LPG also exist on the outer atolls. ULP is used as fuel in motorcycles and boats, and to power generators for electricity production.[7] ULP demand for cars and buses exist mainly

[7]More discussions on the electricity demand and supply is given in Section 3.2.

on South Tarawa and Kiritimati.[8] ULP is used on a large scale both on South Tarawa and the outer atolls. The petroleum products are imported by KOIL from the following companies (and countries):

- ADO, DPK and ULP—Mobil in Fiji Islands;
- Avgas and Jet A-1—Mobil in Australia; and
- LPG—Elgas in Australia. LPG is also imported by KIRIGAS from ElGas in Australia.

ADO, DPK and ULP are distributed (from South Tarawa) in 200 litre drums to the outer atolls in the Gilbert group and Kanton Atoll in the Phoenix group [13]. Kiritimati, Tabuaeran and Teraina Atolls in the Line group get their petroleum supplies directly from Fiji Islands. The distance from these three atolls to South Tarawa is approximately 3300 km while the distance from Fiji Islands is about 5000 km. Therefore, it is more economical to have the petroleum products transported directly from Fiji Islands [13]. Sometimes there are shortages of the petroleum products on the outer atolls due to irregular shipping.

The cost of DPK and ULP on the outer atolls in the Gilbert group is the same as that on South Tarawa because the freight costs are subsidised by the Government of Kiribati (GoK).[9] The cost of ADO on the outer atolls is relatively higher than that on South Tarawa due to the extra costs involved in transportation, which is not subsidised by the GoK. During a recent visit to Kiribati, the cost of DPK and ULP on the atolls in the Gilbert group was found out to be AU$1.10/litre and AU$1.35/litre, respectively. The cost of ADO on South Tarawa was AU$1.20/litre whereas on some of the outer atolls in the Gilbert group it was $1.35/litre.[10] The cost of all petroleum products in the Line group is 2–3c/litre higher than that on South Tarawa [13].

3.1.2. Biomass

Biomass accounts for approximately 25% of total annual primary energy supply in Kiribati [13]. Biomass resources in Kiribati include coconut shells, coconut husks, coconut fronds and fuel wood.

Coconut shells and husks which are the by products of copra production are used on a large scale. Fuel wood comes from *Pandanus* trees, mangrove trees and shrubs, breadfruit trees and sometimes coconut palms.

With copra being produced on a relatively large scale on the outer atolls, there is an abundance of the by-products (coconut shells and husks). Coconut fronds and fuel wood are seldom used on the outer atolls. The trees/palms are mostly cut down for fuel wood on South Tarawa. There is very little forest cover or vegetation in Kiribati to provide other forms of biomass.

Biomass is used for cooking both on South Tarawa and the outer atolls. Biomass is used on a larger scale on the outer atolls than on South Tarawa. Biomass is also used for drying copra (to some extent) mainly on the outer atolls.

[8]There are very few cars on the outer atolls as well. The exact number of cars on the different atolls is not known. Some atolls have only 1 or 2 cars.

[9]ULP is used as fuel in motorcycles and boats, and to power generators while DPK is used for cooking and lighting. Both these products are used on a large scale by the people on both South Tarawa and outer atolls.

[10]The cost varies from one atoll to another.

For approximately 55% of the households on the outer atolls, cooking needs are met by biomass, 30% use both kerosene and biomass and 15% use only kerosene [13].

3.1.3. Solar energy

Solar energy is used mainly in the form of PV in Kiribati. The applications of PV technologies in Kiribati are as follows:

- Lighting (indoor and outdoor)—indoor lighting in houses and community halls and outdoor or street lights;
- Pumping water in villages and schools; and
- Powering electrical devices such as communication devices (phone, fax machine and citizen band (CB) radio), radio, torch, fan and refrigerator.

In total, solar energy accounts for less than 1% of the total primary energy supply in Kiribati [13]. More discussions on PV technologies and its uses in Kiribati are given in Sections 5.1–5.6. For households where solar energy is not being currently used, kerosene lamps and generators (powered by ADO or ULP) are the main sources of lighting.

3.1.4. Wind energy

Wind energy has been used in Kiribati for pumping water. In the 1960s, windmills were installed on Tabiteuea-South, Arorae and Nikunau Atolls. The initial costs of these systems were covered by the World Health Organisation (WHO) and the maintenance was carried out by the Kiribati Public Works Department (PWD), with financial support from the Government of Australia [15].

Most of these windmills that were installed in 1960s are not working today due to some mechanical problems [15]. The exact nature of the mechanical problem is not known but the reason for these wind mills being defunct are because of the lack of availability of trained personnel to carry out maintenance [15]. One or two windmills still operate on Arorae Atoll and one still operates on Tabiteuea-South Atoll [16]. The other windmills have been replaced by solar pumps in the 1990s [15].

Some windmills were also installed on Kiritimati Atoll for pumping water. The current status of these windmills is not known.

3.2. Electricity demand and supply

The demand for electricity exists both on South Tarawa and the outer atolls. The population of South Tarawa (including part of North Tarawa)[11] is served by an electricity grid. There are three diesel power stations on South Tarawa. Two of these are in Bikenibeu Village and one in Betio Islet. The number and the capacity of the generators are as follows [17]:

- Bikenibeu Power Station 1—two 2.6 MW diesel generators;
- Bikenibeu Power Station 2—three 1.4 MW diesel generators; and
- Betio Power Station—one 1.25 MW diesel generator.

[11] Including the following four villages of North Tarawa: Buota, Abatao, Tabiteuea and Nabeina Village.

The two 2.6 MW diesel generators at Bikenibeu Power Station 1 have not been working since September 2005 [17]. These 2.6 MW second-hand generators were purchased in 1960s and due to the "old age," they have now become defunct [17]. Currently, most of the electricity demands are met by the three 1.4 MW generators at Bikenibeu Power Station 2. The 1.25 MW generator located at Betio power station is used to meet demands during the peak periods only [17].

In 2003, the diesel power generation and supply system on South Tarawa was upgraded with assistance from the Japanese Government under its bilateral development programme [18]. The project included the installation of the 1.25 MW generator at Betio Power Station and the upgrading of 16 km of power lines [17,18].

Kiritimati Atoll also has a diesel-powered electricity grid which is for government facilities and tourism purposes only. Recently, there has been a rise in electricity demand and consumption on Kiritimati Atoll due to some (mainly tourism) developments [13].

There are mini electricity grids on the other outer atolls that are used by Island Councils and some private households. Stand-alone portable generators are used in homes, community halls (*maneabas*), schools, Island Council offices, health clinics and stores on the outer islands. Most of these are petrol generators and are operated for only a few hours a day.

In 2002, the electricity consumption by the government, domestic and commercial sectors on South Tarawa were 55%, 30% and 15%, respectively [13]. Fig. 5 shows the population and electricity consumption in Kiribati for 5 different years [3]. In 1987, 1995 and 2003, the per capita electricity consumption in Kiribati was approximately 100, 116 and 200 kWh, respectively. The increase in per capita electricity consumption shows that the electricity demands and therefore consumption in Kiribati has risen significantly over the past decade or so.

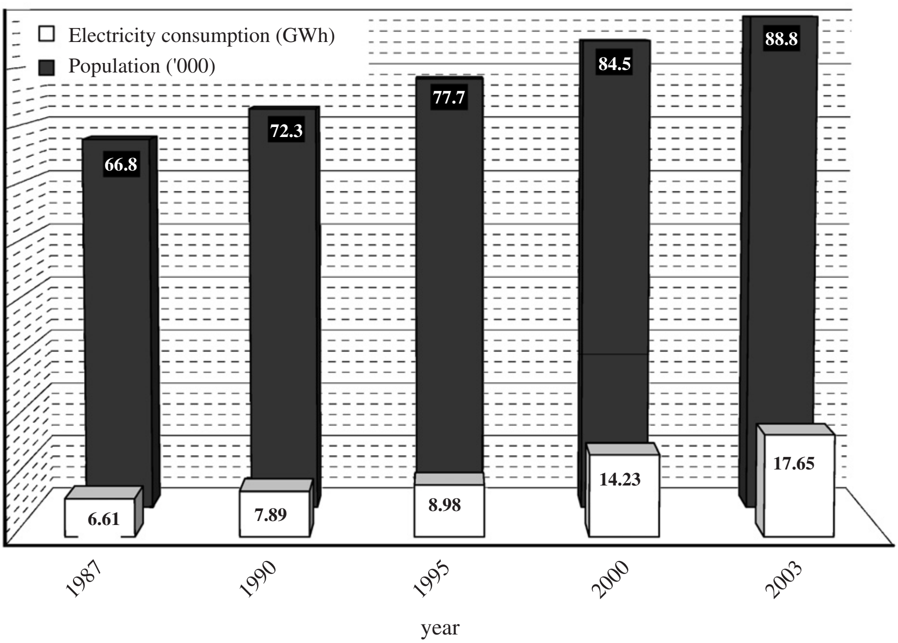


Fig. 5. Population and electricity consumption in Kiribati for 1987, 1990, 1995, 2000–2003.

3.3. Energy institutional framework

The Energy Planning Unit (EPU) which comes under the Ministry of Public Works and Utilities (MWU)[12] is responsible for energy matters in Kiribati. The EPU coordinates the implementation of energy policies and provides assistance and advice on energy-related activities in Kiribati. The EPU also oversees the operation of the following three bodies [13,19,20]:

1. KOIL—imports and distributes petroleum products;
2. Public Utilities Board (PUB)—responsible for provision of electricity, drinking water and sewerage services on South Tarawa; and
3. Solar Energy Company (SEC)—involved with the installation, lease (or sale), service and maintenance of PV systems and components.

In addition to this, the other participants in the energy sector include [13,19,20]:

1. Island Councils—look after the development of communities;
2. KIRIGAS—responsible for the purchase and distribution of LPG;
3. Ministry of Commerce, Industry and Tourism—responsible for regulation of the prices of petroleum products;
4. Ministry of Finance—involved in projects benefiting from international aid;
5. Ministry of Health—involved due to the utilisation of PV for lighting and vaccine refrigerators in health clinics;
6. Ministry of Line and Phoenix Islands—responsible for electricity on Line and Phoenix groups;
7. Public Works Department (PWD)—operates and maintains the electricity grid on Kiritimati Atoll. It is also responsible for the operation and maintenance of solar water pumps and windmills used for pumping water on the outer atolls; and
8. Telecom Services Kiribati Limited (TSKL)—looks after the operation and maintenance of solar-powered public phones on the outer atolls.

4. Solar resource

Kiribati is well endowed with insolation (incoming solar radiation). Both the 180° meridian and the equator pass through Kiribati. The annual average radiation and cloud cover for five different sites in Kiribati is presented in Table 1 [21]. From the data presented in Table 1, Kanton Atoll has the highest annual average insolation whereas London Village has the lowest. These values correspond with the lowest annual average cloud cover for Kanton Atoll and the highest for London Village.

Fig. 6 shows values for insolation from January to December incident on a horizontal surface in Kiribati for five different sites presented in Table 1 [21]. These values are based on satellite observations taken once every 3 h. Each value is an average for a particular month over the 10-year period (1983–1993).

[12]MWU was formerly known as the Ministry of Public Works and Energy (MWE).

Table 1
Annual average insolation and cloud cover values in Kiribati from January to December over a 10-year period (1983–1993) for five different sites: Abaokoro Village (North Tarawa), Betio Islet (South Tarawa), Kanton Atoll, Kariatebike Village (Abemama Atoll) and London Village (Kiritimati Atoll)

Site	Atoll: group	Geographic coordinates	Annual average radiation ($kWh\,m^{-2}\,day^{-1}$)	Annual average cloud cover (%)
Abaokoro Village	North Tarawa: Gilbert	1°467′N and 173°017′E	5.92	65.43
Betio Islet	South Tarawa: Gilbert	1°350′N and 172°933′E	5.98	63.03
	Kanton Atoll: Phoenix	2°50′S and 171°40′W	6.26	56.93
Kariatebike Village	Abemama: Gilbert	0°400′N and 173°933′E	6.10	63.29
London Village	Kiritimati: Line	1°983′N and 157°467′E	5.67	68.58

These data were obtained from the NASA Langley Research Centre Atmospheric Sciences Data.

The average monthly insolation varies from one month to another. For these five sites in Kiribati, the insolation varies from 5.32 to 7.04 $kWh\,m^{-2}\,day^{-1}$. The variation in insolation for the five different sites can be explained using the cloud cover data. January and December have relatively lower insolation values and correspondingly higher cloud cover values. The highest values of isolation are in October for Abaokoro Village, Betio Islet, Kanton Atoll and Kariatebike Village and in September for London Village. During these months, at the respective sites, the cloud cover is the lowest. Kanton Atoll has the best solar resource and the lowest cloud cover. The insolation on Kanton Atoll varies from 5.64 to 7.04 $kWh\,m^{-2}\,day^{-1}$. The lowest insolation values were recorded for Abaokoro Village (5.41–6.65 $kWh\,m^{-2}\,day^{-1}$) which has the highest cloud cover.

5. Current PV applications in Kiribati

5.1. Domestic use—solar home systems (SHSs)

The most widespread application of PV in Kiribati is for SHS. Most of the SHS in Kiribati exist on the outer atolls. Very few households on South Tarawa have a SHS. In most of the households that have a SHS, it is used for lighting only.

Fig. 7 shows a schematic representation of a SHS in Kiribati that is rented from the SEC. These SHS consist of a typical daily load of three 11 W lamps operated for 6 h each and one 0.5 W night light operated for 10 h [22]. In some of the cases, a radio is also operated for 6 h a day.

Not all the SHS in Kiribati are rented from SEC. Some households purchase their own systems. Some systems are funded by donor agencies. For the SEC systems, the users pay a AU$9 or AU$10 monthly fee. These SEC systems have also been partially subsidised by aid funding.

Some of the privately owned SHS are used to power electrical appliances such as a radio, fan and a refrigerator. The size of the privately owned SHS varies from one household to another. During a recent visit to some of the outer atolls in the Gilbert group,

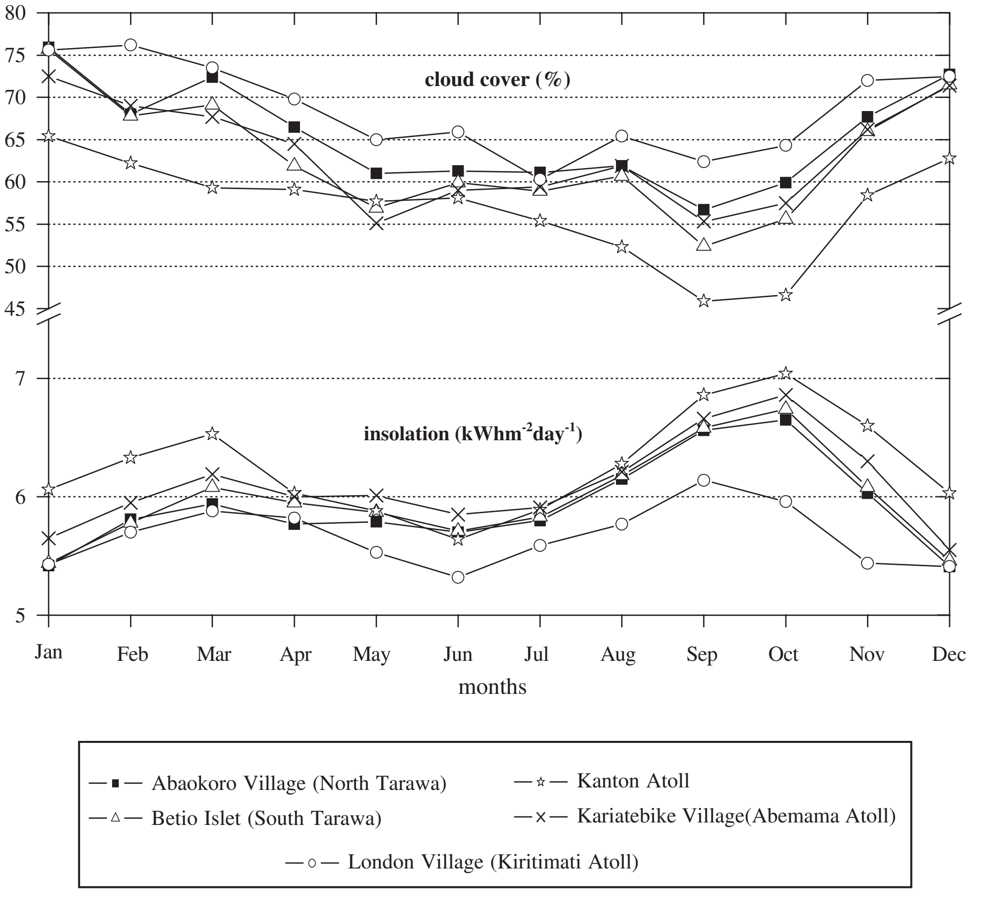


Fig. 6. Monthly average insolation and cloud cover values in Kiribati from January to December over a 10-year period (1983–1993) for five different sites: Abaokoro Village (North Tarawa), Betio Islet (South Tarawa), Kanton Atoll, Kariatebike Village (Abemama Atoll) and London Village (Kiritimati Atoll). *These data were obtained from the NASA Langley Research Centre Atmospheric Sciences Data.*

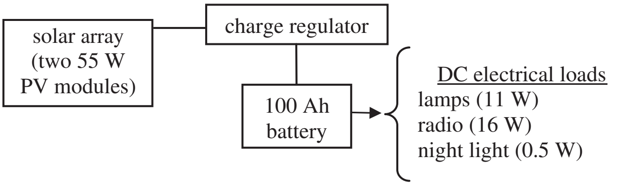


Fig. 7. Schematic representation of a typical Solar Home Systems (SHS) used in Kiribati.

it was seen that the solar panels in the privately owned SHS were between 35 and 55 kW. Most of these panels were used or second hand ones bought from Telecom Kiribati Limited (TKL) and/or TSKL. Some households had only one solar panel whereas others had as many as 10–15.

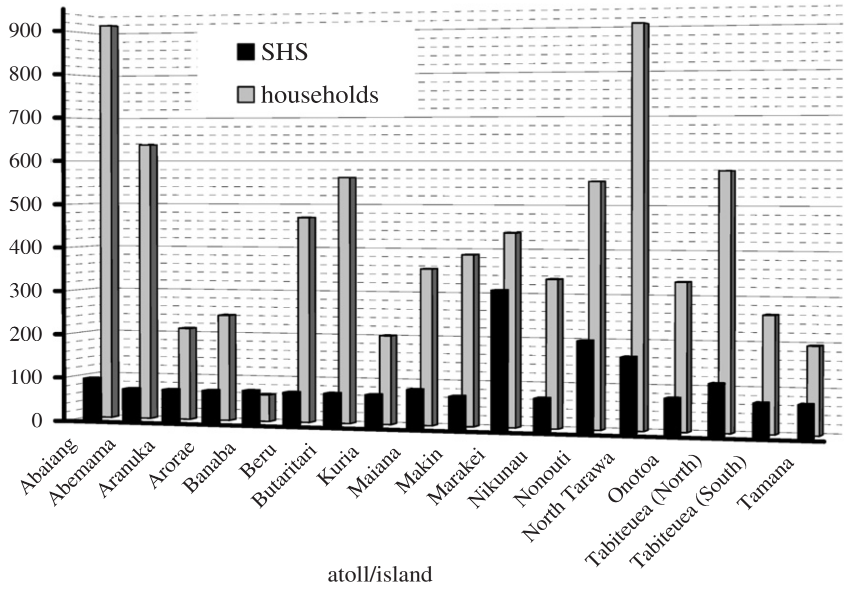


Fig. 8. Number of households and solar home systems (SHS) on respective atolls/islands in the Gilbert group.

In some of the schools on the outer atolls, the SHS were installed in 1980s for lighting in staff quarters and classrooms [23]. Some of these systems are still working but most of them have been abandoned due to failure in replacing the batteries [23].

Of the three groups of atolls, the largest number of SHS exists on the Gilbert group. Fig. 8 shows the number of households and SHS on the different atolls in the Gilbert group [10,24].[13] The highest concentration of SHS is on Banaba Island (77 SHS among 61 households). The lowest concentration of SHS is on Abaiang Atoll. Among the 916 households on Abaiang Atoll, there are 97 SHS. This gives a distribution of one SHS between nine households on Abaiang Atoll.[14]

5.2. Solar community systems (SCSs)

Community halls (*maneabas*) in Kiribati are used for activities such as the conducting of evening devotional services, meetings, entertainment and other social and religious gatherings. SCSs are used for lighting in *maneabas*. The size of these SCSs and hence the number of lights depends on the size of the *maneaba*. The three different sizes of SCSs that have been installed are as follows [23]:

- Four 11 W lights powered by a 200 W PV array;
- Six 11 W lights powered by a 300 W PV array; and
- Twelve 11 W lights powered by a 600 W PV array.

[13]These are the SHS that are rented from the SEC. The exact numbers of the other systems is not known.

[14]There may be some discrepancy in the "number of SHS/household" relationship due to the data being obtained from the different sources. The number of SHS was obtained from SEC (these are the numbers as of now). The number of households was obtained from Kiribati National Statistics Office (These are data from the 2005 census).

Fig. 9 shows the number of solar community systems and the number of villages on the respective atolls [10,23].[15] The highest concentration of solar systems is on Makin Atoll. Both the villages on Makin Atoll have a system each. Abemama Atoll has the lowest concentration of solar community systems. Among 12 villages, there are only 2 community systems.

5.3. Solar water pumping

Solar water pumping was introduced in Kiribati in 1985. By 1993, 11 solar pumps had been installed on the following atolls [15]:

- Arorae Atoll—one solar pump: funded by Save the Children Fund;
- Nikunau Atoll—seven solar pumps (replaced the windmills installed in 1960s): funded by the South Pacific Commission (SPC: now known as Secretariat of the Pacific Community);
- Tabiteuea (North) Atoll—two solar pumps: funded by the Norwegian Government; and
- Tamana Atoll—one solar pump: funded by UNDP.

In 1995, UNDP provided funding for solar water pumps to be installed on Maiana Atoll (two), Aranuka Atoll (one), Nonouti Atoll (two), Beru Atoll (one), Arorae Atoll (one) and Tabiteuea (South) Atoll (two) [15].

In addition to this, discussions with some of the villagers during on-site visits indicated that there are solar water pumps on some other atolls as well. Some of these systems are for use in villages whereas others in schools. The exact numbers and locations of these systems are not known.

5.4. Solar power in health clinics

In 1994, the Canadian International Development Agency (CIDA) provided funds for the electrification of 18 health clinics in the Gilbert group. Each installation consisted of the following two systems [13]:

- Vaccine refrigerator: 24 V 'Sun Frost' refrigerator powered by a 282 W PV array; and
- Lights and CB radio powered by a 110 W PV array.

On all the outer atolls in the Gilbert group, there is at least one health clinic on each atoll that contains a vaccine refrigerator, which is powered by PV. These installations were done by the SEC under contract from the Ministry of Health.

5.5. Solar power for communication systems

The Telecom Services Kiribati Limited (TSKL) has installed and maintains at least one PV-powered high-frequency radio telephone (HF-RT) on each atoll that is within the 3–30 MHz signal range from South Tarawa [25]. Abaiang, Abemama, Butaritari, Maiana,

[15] All the SCSs in Kiribati are rented from SEC.

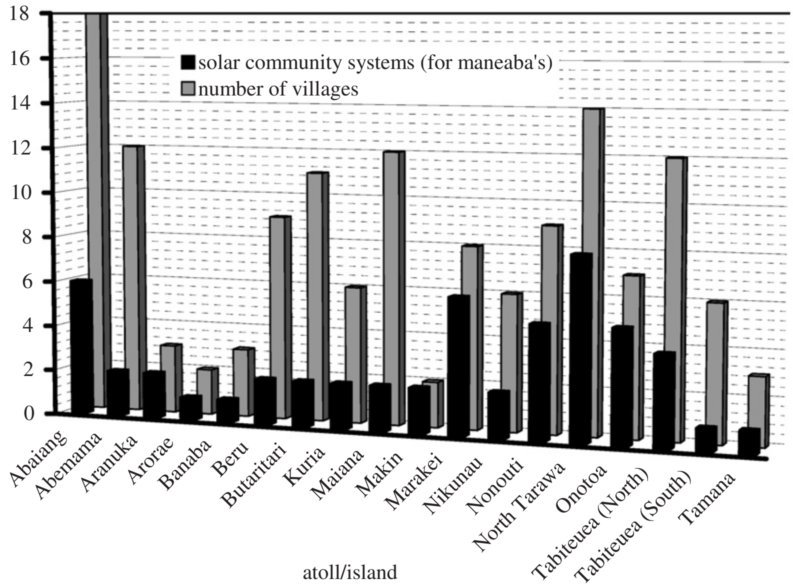


Fig. 9. Number of villages and solar community systems (for *maneaba's*) on respective atolls/islands in the Gilbert group.

Marakei, North Tarawa and Kiritimati Atolls also have Digital Radio Concentrator System (DRCS) telephones, which are powered by PV [25]. A total of approximately 5 kW of solar PV array has been installed on outer atolls for the operation of the phones [13].

In 2004, TSKL installed a satellite earth station on Kiritimati Atoll. This project was funded by the Government of Kiribati. Approximately 5 kW of solar PV array was installed to meet the electricity demands of this earth station [4].

Some schools and health clinics on the outer atolls also use PV for powering a CB radio for communication.

5.6. Solar power for street lights

Some street lights in Kiribati are powered by PV as well. Four street lights on North Tarawa and 40 on South Tarawa (for the Nippon causeway) were installed in 1999 [13]. These systems consist of a sealed battery installed underground in a box to provide a cool and dry environment in order to encourage a long battery life. Power to operate a 20 W fluorescent light is provided by 80 W of PV arrays [13]. These lights are operated for approximately 12 h at night.

6. Concluding remarks and recommendations

In this paper, the current energy situation in Kiribati has been considered with emphasis on the utilisation of PV technologies. The choices for energy supply in Kiribati are presently limited to imported petroleum products, biomass and to a very

insignificant extent, solar energy and wind power. The utilisation of PV technologies in Kiribati at present is largely for lighting. To a limited extent, PV is also used for powering:

- communication devices (telephone, fax machine and CB radio);
- household electrical appliances (radio, fan and refrigerator);
- street lights;
- vaccine refrigerators; and
- water pumps.

Most of these systems have been installed for a number of years now but very little information is available about their contribution to the sustainable development of the communities. According to a report based on an evaluation carried out in 1999, the communities in Kiribati have benefited in a number of ways (both direct and indirect) from PV technologies [22]. Some of the direct benefits were in the communication, education, health and social sectors [22]. Indirect benefits included the convenience of using PV technologies, employment, reduction in time for collecting firewood and reduction in migration to South Tarawa due to availability of lighting and electricity on the outer atolls [22]. This evaluation was carried out only a few years after the installation of these systems. Therefore, the possible long-term benefits of the systems that would promote sustainable development are yet to be ascertained.

Some observations made during a visit to some of the atolls indicate that the communities face many challenges in using and adapting to PV technologies. Some of these challenges include:

- isolation from maintenance services and other expertise required for PV technologies;
- lack of understanding and capacity in using and looking after PV technologies; and
- appropriate use of PV technologies for productive activities such as generation of additional household income.

Several recommendations can be made that will promote sustainable development through the utilisation of PV technologies. For this to happen, sustainable development should be seen in the context of the contribution by the technology to the sustainable livelihoods of the communities and the sustainability of the systems themselves.

Some of the indicators that can be used to evaluate the contribution of PV technologies towards sustainable livelihoods of the communities are [26]:

- Suitability: ability of PV technologies to meet the requirements/needs of the people;
- Effectiveness: the driving objectives for PV technologies and how effective are these objectives;
- Livelihood resilience: effect of PV technology on the financial resources (or savings) of the people;
- Livelihood diversification: effect of PV technology towards peoples' options and choices for income generating activities; and
- Environmental protection—effect of PV technologies on the natural resource base.

Likewise, some of the indicators that can be used to evaluate the sustainability of the PV technologies are [26]:

- Affordability: capacity of the people to afford and maintain the PV technology;
- Effectiveness: cost of energy services provided by the PV technology in comparison to other sources (e.g. diesel) and the profitability of the investment;
- Obsolescence: Insulation from the risk of becoming rapidly obsolete;
- Flexibility: suitability of PV technology to satisfy both current and expanding energy needs (Flexibility of the PV technology to adapt in some way to changing rural needs); and
- Technological capability: availability of human and institutional resources to install, operate, maintain and manage the technology.

Case studies are needed to apply these indicators to the application of PV in rural and remote communities in Kiribati and other Pacific Island Developing States (PIDS). This is the next stage of this work.

Acknowledgments

One of the authors (K. Mala) is grateful to Murdoch University for providing a research scholarship which in part has led to this work. K. Mala would also like to thank the staff of Kiribati Solar Energy Company for information and discussions on this work.

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